Test and Training ENabling Architecture (TENA)

TENA BASELINE PROJECT REPORT

Volume I
Management Overview

Under Secretary of Defense (Acquisition & Technology)

Director, Test, Systems Engineering and Evaluation

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Abstract

The Management Overview provides high-level summary information designed to familiarize the reader with the overall Test and Training ENabling Architecture (TENA) project. The major points of the various technical volumes in the TENA Baseline Project Report are presented in abbreviated form in this Management Overview. It includes important concepts, processes, conclusions, and recommendations at the level of a comprehensive overview. Readers should consult other volumes to gain an in-depth understanding of each topic.

The Management Overview also serves as an expansion of key concepts given in the Executive Summary. These include:

- The Logical Range--a set of resources required to support a specific test or training exercise assembled into a customized system used to conduct that exercise. Resources may come from geographically distributed sites or facilities.
- The Product Line Approach--TENA implementations will be in the form of software-intensive systems. TENA offers a Product Line Approach to building and maintaining these systems that has been proven effective elsewhere and makes sound technical and financial sense for the test and training communities. Preliminary estimates for cost avoidance in our community range from $207 million to $1.1 billion if applied to just 10 systems over the next 10 years. The TENA Cost Study which derived these estimates is contained in Appendix D.
- Continuous Insight--TENA supports and complements radically different approaches to supporting a reengineered acquisition process such as the "Simulation, Test and Evaluation Process" (STEP). In addition to its other roles, TENA offers Continuous Insight to critical data to support informed customer and management decisions about resource needs, capabilities, and investments.
- Evolutionary Implementation--TENA offers a revolutionary response to current and expected test and training range and resource needs; however, the implementation of TENA is evolutionary. Facility managers, customers, and other stakeholders control the rate of implementation by deciding which capabilities provide the best value solutions to their needs. The TENA Transition Plan offers an approach for this evolution.

This Management Overview also discusses lessons-learned from the two-year TENA effort and offers recommendations based on those lessons. The recommendations supplement and/or expand those given in the Executive Summary.

The opinions, ideas and recommendations presented in the TENA Baseline Project Report are the views of the TENA Project Team and do not necessarily represent those of the Sponsor.

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Purpose

The purpose of the Management Overview is to introduce the reader to the Test and Training ENabling Architecture (TENA) project and to provide summary information in a concise format about the other technical volumes. This volume provides background and insight to TENA project goals and objectives. Additionally, major concepts, processes, and recommendations are presented. Appendix C is an example scenario that may be used for validation and Appendix D contains the TENA cost analysis study for software reuse.

Readership

The Management Overview is intended for range management and operation directors and others in range or test and training facility management oversight roles. Additionally, DoD and Service T&E and training program managers will find this volume useful. Detailed technical information is not presented here, but is found in the appropriate volumes of the TENA Baseline Project Report. However, enough information is available for the reader to understand what TENA has accomplished during the first two years and to gain some insight into our plans for the future.

Relationship to Other Volumes

The Management Overview contains summary information about the Technical Reference Architecture (TRA), the Product-Line Approach, the Logical Range Business Process Model (LRBPM), the Integrated Validation and Verification (IV&V) Plan, TENA Requirements, and the Transition Plan. The TENA Application Concepts volume

introduces the concept of the Logical Range as a means of explaining the relationship between the TENA Object Model and the LRBPM.

Volumes of the Baseline Report are designed to be standalone documents, upgraded over time as new information is discovered. The PLA is fundamental to the cost savings required of DoD ranges in the future, but also to breaking the paradigms of the present. A Glossary of Terms and Definitions is provided. Other supporting project information and documentation is presented in volume X. Readers of this Management Overview are encouraged to seek additional detailed information by consulting the appropriate volume.

PROJECT NEED

TENA is part of a coordinated response by the Central Test and Evaluation Investment Program (CTEIP) office to several current and emerging challenges in the test and training range and resource community. These include:

- Reducing software development and maintenance cost,
- Utilizing common instrumentation at multiple facilities,
- Responding to the increased demand for multiple-site exercises and/or exercises which cross T&E/training or live/virtual/constructive boundaries, and
- Responding to the increased demand for consistency of information between facilities and across phases of the acquisition process.

PROJECT PURPOSE

The purpose of the TENA project is to respond to these challenges through the establishment of an architecture that efficiently and effectively fosters the sharing, reuse, and interoperability between cooperating Department of Defense (DoD) test ranges and facilities, training ranges, laboratories, and other modeling and simulation activities. The expected synergism will permit efficient and effective testing of new and enhanced weapons systems and will vastly improve the scope and fidelity of worldwide joint/combined training.

PROJECT HISTORY

The Test and Training ENabling Architecture (TENA) project concept was formulated in FY 95 by a multi-Service working group. This concept was endorsed by the Test and Evaluation Reliance Investment Board (TERIB), the Board of Operating Directors (BoOD) and the Test and Evaluation Resource Council (TERC).

The Navy is the CTEIP Resource Manager for this project, and has established a Joint Project Office (JPO) for the management of the project activities at the Naval Undersea Warfare Center (NUWC) Division, Newport, RI.

Shortly after assembly of the Joint Service Team, several critical observations were made:

- The key to interoperability is not connectivity alone, but rather understanding communications content. This was best promoted by defining an open, object-oriented software architecture that could be used by both legacy and newly built systems.
- The process used to plan, schedule, and otherwise coordinate a multiple- facility, multiple-service exercise must be integral to the development of the architecture, or the capabilities it offers might never be fully utilized.
- The architecture must be conducive to refinement over time and coexists with facility-unique applications. This requires a disciplined architecture development/refinement process. The team adapted the Defense Information Systems Agency (DISA) domain-engineering approach to help develop the architecture and recommends the Product-Line Approach to implementation and life-cycle maintenance.
- Significant investments are being made in other closely related areas such as, Defense Modeling and Simulation Office (DMSO), High Level Architecture (HLA) and the Joint Modeling and Simulation System (JSIMS) program. TENA must leverage as many of these efforts as practical.
- The TENA concept is radically new to our community. Planning for transition is key to its ultimate acceptance.

STATUS

The project team tested its architecture development process in FY96 producing a "Pilot Architecture." This work was reviewed in several public forums and refined in FY97 into the current "Baseline Architecture." The TENA Baseline contains sufficient detail to continue further analysis and risk reduction efforts and is a good vehicle for discussion, experimentation, and refinement. It is not yet appropriate to use these documents as the blueprint for a major system development. After community feedback, results from risk-reduction prototypes, experiments, and other ongoing efforts are synthesized, the cognizant TENA Baseline documents will be updated as "TENA Rev 0." TENA Rev. 0 will be the appropriate source of design information for a TENA-compliant system implementation.

New paradigms have emerged since the end of the Cold War for military systems acquisition and utilization. These new paradigms include reduced acquisition costs and joint Service interoperability. These changes have caused the test and training communities to be faced with a combination of reduced funding and the requirement to test and field new, more advanced and interoperable weapons systems. Under current and future budget constraints, the T&E and training communities will need advanced, more cost-effective technologies in order to provide the necessary capabilities for these upcoming systems. A high-level study of the cost of development and maintenance of software at Major Range and Test Facility Base (MRTFB) ranges clearly shows the value of a Product Line Approach [TENA, 1] to software development and support.

In fact, the study, available in Appendix D, showed that by implementing a PLA and serving 10 range sites we will save approximately $207 million in software development costs and $543 million over ten years in cumulative development and maintenance costs. These savings compare to experiential data from product-line success stories. We can use these savings to improve other areas of the test and training support structure instead of paying three, five, ten, or twenty times to develop and maintain the same functional software at multiple sites.

The identification of a need for community-wide interconnectivity and interoperability was documented as early as 1992 in a study by the Defense Science Board. In that study, the Defense Science Board concluded that the Department of Defense (DoD) should fully link test ranges and facilities, training ranges, laboratories, and other simulation activities. In June, 1994, the Joint Chiefs of Staff (JCS) report on "Review of Requirements to Electronically Link Training Ranges" stated that joint training range requirements do exist for electronically linking single range complexes to constructive/virtual simulations.

In order to test modern weapon systems and/or provide for realistic training activities, we need to prepare for a significantly expanded capability to transfer various types of information in near real-time between geographically separated test and training locations. In addition, we need to enable increased use of modeling and simulation (both virtual and constructive) with test and training range facilities.

Current planning challenges to the DoD for supporting the future investment strategy rely on the development of a common range architecture to promote cost effectiveness, range interoperability, and leverage investments. TENA is a coordinated response by the CTEIP office to these challenges.

TENA will provide DoD with a common architecture to guide the acquisition of 21st-century systems. The architecture will enable the necessary trends toward integration of test and training capabilities. The expected synergism will permit efficient and effective testing of new and enhanced weapons systems and will vastly improve the scope and fidelity for worldwide joint/combined training. Additional benefits include: reduced cost to integrate new instrumentation to a common architecture vs. customizing instrumentation for each range and cost savings associated with reusing major software components across multiple test and/or training facilities. The TENA cost study shows significant financial advantages to the test and training community from just one (system reuse) of TENA's expected benefits.

RATIONALE FOR CHANGE

Radically different approaches are needed to meet the demand for increased software functionality at a time when the Department of Defense has less money and staff to accomplish this task. New techniques, such as the Product-Line Approach, can be applied to meet these challenges.

The Product-Line Approach can offer specific advantages over a project-oriented development strategy. [Brownsword, 1996] Development time and cost are significantly reduced. Organizations build core competencies, which are concentrated areas of knowledge that allow them to make more productive use of their staff. Products are engineered through recognition of changes within fundamental requirements or product-line architectures, rather than built from scratch. In addition, under the Product-Line Approach, the range community can provide specific guidance to suppliers for vendor qualifications, development standards, and product definitions.

The Product-Line Approach to developing and maintaining DoD systems is supported by the Office of the Secretary of Defense. The Air Force is currently planning to implement product-lines, consistent with direction and guidance from the DoD. A product-line strategy is consistent with and complements the ongoing acquisition reform and streamlining initiatives within the DoD and Air Force. [Perry 1994] [Lightning Bolt] [Dikel, 1997] [Macala, 1996]

By exploiting commonalties and controlling the variability across related systems, the range community can develop strategies that will enable the fielding of systems faster, cheaper, and with added capability for the T&E and training.

Within this constraint, the Product-Line Approach will result in:

- Consolidation of core resources and competencies through identification of key business areas,
- Increased quality through the use of assets that are well understood and proven through retesting during multiuse,
- Building of tailorable features into assets to meet more than one user's needs,
- Minimizing of number of assets--reducing overall and repetitive development costs,
- Reduction of risk in software performance through known performance of assets,
- Improved time to production through reuse of technology, design, and assets,
- Increased interoperability through reuse of common architectures, interfaces, and protocols, and
- Reduced training requirements for operations and Operation & Maintenance (O&M) through similarities of components.

PRODUCT-LINE IMPLEMENTATION

Many familiar examples of product lines exist in the manufacturing and retail areas. One is the automobile, for which companies use the same engines, transmissions, frames, factory infrastructure, etc., in different models of cars that are marketed for different purposes. Volume II, Appendix C contains specific information about CelsiusTech and Hewlett-Packard success in implementing product lines.

In early 1993, the Space Command and Control Architectural Infrastructure (SCAI) project was selected as the Air Force demonstration project in a collaborative venture with Loral (one of the three Software Technology for Adaptable and Reliable System (STARS) Prime Contractors) to exploit the technological advances made by STARS. The project is building a space tracking and warning application. Prior to forming the partnership, the Space and Warning System Center (SWSC) had already established an excellent head start in the area of *domain-specific reuse* through its work with TRW on a reusable architectural infrastructure -- culminating in the Reusable Integrated Command Center (RICC) [Bristow93]. This architectural infrastructure provides services and construction techniques that greatly simplify developing and maintaining systems in the space and warning domain. In effect, a new way of doing business, in which its entire product line of applications will ultimately be managed according to a coherent strategy now centered around a common architectural approach. [Bristow, 1996]

RANGE DEVELOPMENT ORGANIZATION

A range development organization operating under the PLA concept will perform the following tasks:

- Utilize the core architecture for all range-related products,

- Develop range-unique component assets for that architecture,
- Provide range products to range customers, and
- Support the implementation and maintenance of the development and execution environments for ranges.

There are four groups within the range development organization:

- The Architecture Group produces the TENA product-line architecture definition (Technical Reference Architecture and domain specific architectures) for all range development organization products. The architecture group also collaborates in building specific applications by recommending use of product-line assets to the range product development groups based on user requirements and by analyzing needs and tailoring the product-line architecture for production of the application.
- A Component Asset Group develops assets within specific areas of range expertise for use in range products. The asset group also defines and evolves product-line architectures with the Architecture Group.
- The Product-Line Support Group defines the development and execution environments for range products.
- Range Product Development Groups develop and deliver range products for users in the field. They develop a system architecture using the product-line architecture, including the technical architecture and components. These groups will generally be located at major range facilities or Service laboratories.

DEVELOPMENT OF SYSTEMS IN A PRODUCT LINE

The process for developing systems with a product-line approach differs from the current process in two ways. These are:

- *Development from standard architectures - A group of related systems shares a common structure defined as a product-line architecture. In addition to structural properties, the product-line architecture defines the components (mandatory, optional, alternative), component interrelationships, constraints, and guidelines for use and evolution in building systems in the product-line. This architecture must support interoperability and component sharing with systems developed outside the product-line. A new system is built by using the technical reference architecture to produce a system architecture from which an implementation is constructed.*
- *Development using product-line assets - New systems are composed, adapted, or generated by populating a system architecture derived from the technical reference architecture. To the greatest degree possible, the system architecture uses existing product-line assets. This approach to development includes formal tracking of the product-line assets and identification of opportunities for reuse of the assets in other product-lines. The new system architecture and any developed or modified assets become core assets for future development in the product-line.*

The product-line assets and environments are key to development of range products.

They also define variations among range products.

Working With The User

Under the product-line concept, the Range Product Development Groups are the designated developers of individual range products and work with the other groups within the range development organization to sustain the product line and its assets. Range users work with the Range Product Development Groups to define operational requirements and deploy systems using product-line assets, as well as their own components. Users and test and training organizations may also rely on the product-line organization to provide domain expertise in key technology areas, such as radar, communications, and network control, rather than maintaining organic expertise in every area.

BENEFITS AND CHALLENGES

By exploiting commonalties and controlling the variations across related systems, the range community can develop strategies that will enable the fielding of systems faster, cheaper, and with added capability for test, evaluation, and training. This is essential in the "test in a training environment" paradigm of the future. However, for the product-line concept to work, there must be a fundamental change required in the way system requirements are defined. The user (customer) will drive the PLA concept, as well as the new Logical Range business methods in the future. TENA is designed to enable that shift in methodology.

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- Composability

Distributability

Extensibility

Flexibility

Interoperability

Maintainability

Malleability

Modifiability

Modularity

Portability

Reliability

Reusability

Scalability

Sharability

Understandability

Usability

TENA is defining an architecture to enable sharing of information, interoperability of selected resources, and reuse of major software components within the test and training communities. As a result, the cost of integrating new instrumentation systems will be reduced as more and more systems migrate to the common architecture baseline. Furthermore, there is an immediate need for the architecture to help guide investment decisions concerning the modification of existing systems and the acquisition and location of planned assets necessary to provide new capabilities.

The architecture described in volume IV establishes a basis for a line of products for training and T&E facilities. TENA abstracts and defines common characteristics and requirements and provides levels of structural detail and coordination protocols that allow the facilities to function as a integrated system in a well-coordinated, efficient manner and meet requirements for facilities to schedule and share assets and to interoperate. The approach followed is hierarchical with a Technical Reference Architecture to satisfy enterprise-level concerns and various system architectures which satisfy lower-level concerns.

This architecture is based on defining a Technical Reference Architecture [TENA, 3] which is instantiated as required for each system architecture and adapted through extension to meet local requirements. The TRA is an abstract architecture that provides the structure and coordination capabilities to form the essential foundation around which a complete system architecture is built. The TRA specifically addresses the requirements that derive from enterprise-wide concerns. The current TRA imposes a structure that will be inherited by system architectures in the TENA Enterprise including: open air ranges, integrated system test facilities, hardware in-the-loop facilities, etc.

Figure 3 illustrates the collection of design decisions, system information, and how those relates to architectural constructs.

Figure 3 TENA Architectural Construct

The large triangle represents the complete collection of design and implementation decisions made about a system within its boundaries. The decisions are sorted so that the most powerful, that is, the decisions that have the greatest effect on the system are located towards the apex while the more local decisions that affect relatively small parts of the system are located towards the base. The base of the triangle represents the implementation of the system that contains all of the information about the system. An architecture includes a collection of design decisions about the structure or coordination of a system. Those decisions act as constraints on the further design and implementation of the system. The concern is to make sure that the right set of decisions has been incorporated into the architecture, yet to incorporate a minimal set to prevent designers from being excessively constrained and precluding innovation.

In essence, TENA is attempting to provide a basis for an enterprise-wide system. The level of integration required to achieve the interoperability and sharing is similar to what an enterprise needs to support an integrated business system. The adoption of the Product-Line Approach for this environment is a decision that supports the reuse goal as well. Critical to the success of a product- line is an architecture which provides unifying concepts that address technical requirements across the product range yet which is capable of providing reasonably efficient infrastructure capabilities for each product. In the integration of T&E and training facilities, this is a difficult job because of the variety of facilities and site-specific performance requirements. A very effective mechanism for dealing with this diversity over a large domain is to base the architecture on a technical reference model or architecture. This allows the system architects a mechanism to insure that basic capabilities are available across the entire product line while allowing individual products or segments of the domain to customize specific system architectures to meet their needs.

The architecture described below and in volume IV is the TRA identified above. The specification of system architectures is deferred to other documents to be produced as the system architectures are defined. Designers of those architectures are the primary users of the TRA.

TRA DESCRIPTION

The TENA Technical Reference Architecture is composed of three main constituents. These are the Object Model, the TENA Core, and TENA standards and protocols. The Object Model of the TENA describes the structure of and dynamic relationships between components of the resulting system and includes multiple views or models. The model depicted in this document is centered on the view that characterizes the domain or problem space. Other models that will become incorporated over time include the implementation model of the system (solution space), which depicts the artifacts created as parts of the system, and the information model of the system.

The TENA Enterprise is the collection of TENA-compliant systems that are joined together via appropriate communications facilities as an integrated, interoperating system of systems. Components and systems are implementations of elements of the Object Model integrated with the TENA Core. Facilities and systems join as part of the TENA Enterprise or operate in an isolated, stand-alone mode. The architecture specifies a protocol used by these systems to announce their intent to join the enterprise system. Other systems which are joining or have joined the enterprise system respond to an announcement of intent to join (or resign, as appropriate) establishing a distributed and fully replicated enterprise state shown in Figure 4.

Figure 4 The TENA Enterprise

All facilities and all systems within the enterprise are able to recognize and interact meaningfully with all other systems that have joined the enterprise. The network connections required to join the enterprise are predefined and well known to all TENA-compliant systems. Individual systems can join or resign as required, and no single system or set of systems is responsible for control of or maintaining the state of the system as a whole.

The baseline TENA Object Model is described below. The model is a conceptual view of the major elements (objects), operations, attributes (data items) and relationships of the Logical Range.

OBJECT MODEL

The TENA Object Model (OM), provides an object-oriented view of the aspects of TENA visible to the Customer, Exercise Planners and Operations staff when conducting a Logical Range test/training exercise. It relies on the TENA Core and the TENA Logical Range Business Process Model and supports the Logical Range application.

The OM incorporates the utilization of browser-based technology within the Logical Range Support Tool for full implementation.

The Object Model presented in Figure 5 below, represents several views of a test and/or training range that are recognizable and meaningful to range users. The view presented here is primarily a model of the domain of interest. We present only a portion of this domain model in Volume IV both for reasons of clarity, so we can illustrate the breadth of the domain as well as some of its details, and because the analysis is a continuing process. We have concentrated more on OARs in the initial analysis because of availability of information and subject matter expert personnel. The analysis will extend across the entirety of the domain of T&E and training facilities as TENA proceeds.

Figure 5 OM Level Three Domain Model

TENA CORE CAPABILITIES

The TENA Core is composed of an integrated union of information management service groups and mandatory applications that are standard across all instances of the TENA facilities. The information management services provided by the TENA Core have been logically grouped into 5 service groups, and 4 required for mandatory applications. See Figure 6. These information management service groups are:

- Distribution services,
- Message services,
- Connection services,
- Clock services, and
- Infrastructure support objects.

The required or mandatory applications are:

- Network Manager,
- Asset Manager,
- Execution Manager, and

- Initialization Manager.

The service groups are best understood when viewed as logical groupings of closely related service groups. The first three service groups, Distribution, Message, and Connection Services, are responsible for the object-based subscription service that provides for information movement within the system, whether data or control. Distribution services provides the only procedural interface within the infrastructure services. Access to all other assets including all other services of the infrastructure is via this object-based subscription service.

The remaining two groups, Clock Services and Infrastructure Support objects provide capabilities for coordinating time on the logical range and internal functioning of the infrastructure.

The four required applications, the Asset Manager, the Execution Manager, the Initialization Manager, and the Network Manager are responsible for supporting the planning, scheduling, and execution of tests/exercises on instances of the logical range, including managing any initialization data required.

Figure 6 Conceptual Model of the TENA Core

STANDARDS AND PROTOCOLS

Various standards will be specified at different levels within the hierarchy of the architecture during the process of developing TENA and the systems that it supports. Many of these standards will be specified at the level of the system architecture to support specific types of facilities. Other standards will be specified at the implementation level. These standards are specified in response to the need to support certain required technologies, platform-provided capabilities, information processing conventions, and information exchange resources. Since these technologies and resources evolve over time and are replaced as they become obsolete, the standards incorporated into the TENA will evolve in response to the changing needs of facilities. A conscious effort has been made in defining the architecture to isolate places where applicable standards are subject to evolving at a relatively rapid pace and encapsulating those loci with well defined and stable interfaces. This results in an architecture where standards with wide applicability across the architecture (at the level of the TRA) are restricted to those known to be stable over time.

TENA BRIDGE

TENA has been structured to effectively support an orderly transition from the current set of facility assets to those envisioned as the long-term goal. The transition will, of financial necessity, have to be gradual which allows a progression of relatively small and low-cost steps so that facilities can begin to enjoy benefits from TENA early in the process. Certain system components, primarily the TENA bridge, have been included to support this transition.

We anticipate that the initial transition step a facility would make is to wrap the entire facility or some portion of it with a TENA bridge and use that bridge to connect to the enterprise. This will enable the bridged facility to interoperate with other facilities at some level and allow the enterprise facilities to recognize its existence. Ultimately, systems will be built with components that directly access TENA Core Capabilities and allow those components to be used with little or no modification across facilities and systems in a *plug-and-play* manner. Facilities can decide to encapsulate smaller and smaller collections of assets within a bridged system and either build from scratch or upgrade existing systems to be fully integrated with the TENA Core.

HIGH LEVEL ARCHITECTURE AND TENA

An important goal of the TENA architecture is to reuse the results of other DoD architecture development efforts, when appropriate. The DoD High Level Architecture (HLA) was being specified and developed during the time that the TENA project was initiated. Similarities in goals were obvious. Furthermore, since the TENA is required to support training and to incorporate simulations, there was good reason to believe that some of the solutions derived for the simulation community would be appropriate for the test ranges as well. The results of the HLA Engineering Protofederation during FY96 confirmed the promise of HLA for test and training range applications, but also highlighted some important HLA challenges that remain ahead, particularly dealing with performance of the Runtime Infrastructure. Furthermore, briefings presented by the TENA team during FY96 posed some additional concerns regarding the application of HLA to the test and training ranges.

The TENA architecture has not been limited to the views and concepts included in the HLA. Instead, the team based the derivation of the TENA Baseline architecture on early results of the requirements analysis and business process modeling tasks. Several members of the TENA Integrated Product Team (IPT) team attended technical meetings on the HLA and tracked the evolution of that architecture. The HLA work influenced the thinking of the TENA architecture IPT team, but did not constrain its solutions.

The TENA architecture team was charged with developing an architecture to support a business enterprise. The requirements included the need to manage resources and integrate a wide variety of components related to all aspects of operating T&E and training facilities. This is well beyond the scope of allowing components to exchange data. The current concept for the HLA addresses a much more restricted set of issues. It provides a set of basic capabilities that allow components (federates) to be constituted into an execution, supplies some fundamental simulation functionality (save, restore, pause, resume, etc.), and enables the federates to exchange data. Thus, while the HLA may provide essential functionality that TENA can make use of, it falls well short of the type and amount of support that TENA needs to provide to the systems it supports. This is by no means a shortcoming of the HLA since it has never been the intent of the HLA to support this wide range of system capabilities.

The Logical Range Business Process Model (LRBPM), outlines and defines the steps and activities to be followed when conducting a Logical Range test or training exercise. In conjunction with the TRA it supports the TENA Application Concepts for the execution of a test or training exercise. The LRBPM [TENA,4] relies on the utilization of browser-based technology proposed in the Logical Range Support Tool for full implementation. Development of this tool will be done following the Product Line Approach as discussed in Volume II of the TENA Baseline Report. (LRBPM defined terms appear in italics)

The Logical Range is a range without geographic boundaries. An instance of the Logical Range is created at a point in time when specific customer requirements dictate a need for interoperability, sharing or reuse of resources. Resources or assets may include platforms, instrumentation, software modules, test or training exercise plans or data products, models, simulators, air or water space, computers and stimulators. The Logical Range meets *customer requirements* when it creates a dynamic entity which schedules and integrates resources, plans, executes and delivers a *customer data package*. It allows facilities and test or training ranges to expand their capabilities and provide more comprehensive resources and services assembled to meet *customer requirements*.

The LRBPM was developed to enable the business processes that pertain to building and using a Logical Range. It supports all phases of test and training conduct. The LRBPM provides a standard process that maintains current test and training business processes integrity and functionality but allows for distributed, multi-site, and multi-Service exercise development. TENA Project staff followed a three-step process to develop the LRBPM. First, business process information was collected from interviews with test and training subject matter experts from all Services, and range business process documentation (See Appendix D of the LRBPM). Second, the staff created a generic business process model that mapped current test and training ranges business process (See Appendix E of the LRBPM). This generic process was reviewed and validated by test and training subject matter experts. Third, the staff developed the LRBPM to support test and training in the Logical Range environment.

The LRBPM is a *customer* and *scenario* based process. A *customer* is defined as a person, command, or organization that has a need to sponsor a test or training exercise. A *scenario* is the combination of environment, participants, events and resources which can be used to meet the test or training *customer requirements*. In the LRBPM the *customer* has control of all the activities and collaborates in the scenario definition, planning, scheduling, executing and reviewing phases of the Logical Range test or training exercise. A *scenario* is one viable way of meeting *customer requirements.* There could be one or more viable scenarios. The *Logical Range scenario* is the particular scenario selected to be utilized for planning of a specific instance of a Logical Range. The Logical Range scenario is composed of a *mission space* definition and Logical Range Resources. *Mission space* corresponds to the combination of environment, participant and events parameters that will provide information for *primary resources assignment*. Logical Range primary resources correspond to essential or high-level resources that are paramount for the Logical Range. The Logical Range resources include facility or range specific assets that are required to support primary resources in the execution phase. These include both secondary and logistics resources.

The LRBPM commences with inputs of *customer requirements* and concludes when a *customer data package* is delivered. The LRBPM imposes no time constraints on the instantiation of a Logical Range. It allows for iterative activities to revisit earlier steps in order to change parameters or adjust specifications. The *Logical Range manager* and the *customer* are two of the principal roles defined by the Logical Range. The *Logical Range manager* is one of the mechanisms that enables the process and is considered a *subject matter expert*. The *Logical Range manager's* role is to aid the *customer* with every step of using the Logical Range capability. The *Logical Range manager* could be facility or range program managers, customer representatives, single face points of contact or other facility or range specific customer liaison.

The LRBPM provides for process improvement of each phase by compiling managerial and operational understanding from *lessons learned*. *Lessons learned* apply to all phases and should be reviewed by the *Logical Range manager, customer* and facility or other range personnel involved in the Logical Range instantiation.

HIGH-LEVEL PROCESS DEFINITION

The LRBPM is composed of five major activities: Define a Logical Range Scenario, Schedule Logical Range, Plan, Execute Plan, and Closeout, as shown in Figure 7.

Figure 7 Conduct a Logical Range Test or Training Exercise Process

Define A Logical Range Scenario

Figure 8 shows the high-level diagram of the LRBPM.

Figure 8"Conduct a Logical Range Test/Training Exercise" A0 Diagram

Define a Logical Range *scenario* initiates the process by establishing the boundaries to be utilized to define *scenarios.* In this first activity the Logical Range *manager* and the *customer* define the Logical Range *scenario characteristics*. These characteristics include the type of test or training exercise, environment attributes, event definitions, participants or particular resources. These are identified as parameters for scenario definition to the Logical Range *support tool.* There may be several viable *scenarios* that will satisfy *customer requirements.*

These *scenarios* are then matched to current facility or range capabilities to determine if required capabilities do exist to support the desired scenarios. In the event that *scenario requirements* cannot be matched to an existing facility or range capability, the *customer* and the Logical Range *manager* can redefine the *scenario characteristics* or conclude that new capabilities are required for successful *customer requirements* matching. If new capabilities are required, then facility or range management will evaluate the Unmatched *requirements* to determine if the time and/or cost of developing those new capabilities could still allow for *customer requirements* satisfaction. The ability to consistently and reliably provide this information to facility and range managers is a tremendous value added to the acquisition management process. Once the *scenario requirements* have been matched, a *cost estimate* is developed for each Scenario. With a *cost estimate*, *scenarios* and *customer requirements* as inputs, the Logical Range *manager* and the *customer* select the Logical Range *scenario.* The Logical Range *primary resources schedule requirements* are also defined at this time.

Schedule Logical Range

The second phase of the LRBPM is *schedule* Logical Range. During this activity the Logical Range *primary resources assignment* and the Logical Range *working schedule* are developed. First, the *primary resources availability report* is developed by browsing the Joint, Service Ranges/Facilities schedules. TENA-compliant [TENA,1] facilities and ranges will post their Logical Range *resources* scheduling information so that it is available to the browser-based tool. The Logical Range *support tool* will search for the availability of the *primary schedule requirements* and will develop the *primary resources availability* report containing among other data, the availability dates and the corresponding facility or range.

The second phase of the scheduling activity is to *optimize the schedule* using an optimization tool to develop the most viable Logical Range *working schedule* and Logical Range *primary resources assignment*. The working schedule will be used for planning and executing purposes. It is labeled "working" to imply the volatility of the information contained within. The Logical Range manager and the customer make changes or time adjustments until the execution phase begins.

Plan

The third phase of the LRBPM is to plan the Logical Range test or training exercise. During this phase a detailed Logical Range *plan* and a *refined cost estimate* are developed. This activity establishes the Logical Range *operating financial environment* by creating the *financial documentation*, defines and coordinates *secondary* and *support requirements* which are contained in the *logistics annex*, refines the *cost estimate*, and compiles the Logical Range *plan*. Support *requirements* include among other communications channels, computation requirements, financial, display and data reduction or transfer. The *logistics annex* outlines the safety, environmental, air/water space and other plans. It includes particular chapters dedicated to facility or range specific documentation. The Logical Range *plan* is the single document that contains all Logical Range information. The level of detail required on each plan is determined by *customer requirements* as well as by the Logical Range *procedures* and the *facility/range procedures* which control each Logical Range *primary resource*.

Execute Plan

The fourth phase of the LRBPM is *execute plan*. This activity provides the Logical Range manager with the steps to follow during the execution phase which commences with *setup* and concludes with a *debrief.* During this phase of the Logical Range instantiation, the Logical Range *manage*r will utilize as guidance the Logical Range *plan. Financial data* as well as event Logs are collected during execution to be used during the Closeout phase. Once the execution has been completed a Preliminary Data Package is prepared. The last step of the execution process is to Debrief the execution of the test or training exercise. The Logical Range *manager, customer*, and *supporting staff* will be involved during the debrief.

Closeout

The final phase of the LRBPM is the *closeout* phase. At this time four activities are performed which commence with *collect customer feedback* and end with *resolve/close payment/data issues*. The final outputs of the *closeout* phase are the *customer data package* (which is delivered once any data or financial issues have been resolved) and the Logical Range *lessons learned*. Collecting *customer feedback* provides the Logical Range *manager*, as well as facility/range Logical Range *resource* provider with valuable information regarding managerial, operational and performance feedback regarding the Logical Range instance. The *customer data package* is verified with the purpose of allowing the Logical Range *manager* and the *customer* to review the results and determine whether provided data products comply with the plan specifications and *customer requirements.*

Payment issues are identified by comparing the *financial data* collected during the execution phase to the *financial documentation* and *refined cost estimate*. Some *payment issues* that could arise include deviations from the *refined cost estimate* or funding not received by any Logical Range *resource* provider. In order to properly close a Logical Range instance two things are normally required, all financial and data issues must be resolved and a *customer data package* must be delivered to the *customer.* A compilation of specific managerial, operational, performance, and financial *lessons learned* is the final product of the process. The Logical Range (LR) *lessons learned* will be kept on a Logical Range repository for future review of Logical Range users.

IMPLEMENTATION ISSUES

As distributed exercises or tests are integrated with traditional autonomous range tests, there are a variety of business process related issues that need to be addressed. These include:

- Resolution of scheduling and planning conflicts at all levels (customer, range, Fleet, joint).
- Integration of Logical Range scheduling process with current scheduling process. Parallel operation of traditional range with Logical Range.
- Contingency planning with respect to live participants (changes in weather, security, safety, schedule, priority, etc.). What feedback loops accommodate this?
- Test/training community objective misalignment and conflicts (acquisition test, operational test, small team training, and theater-level training).
- Selection of assets to be made interoperable (and funding to do it).
- Execution of simultaneous overlapping logical ranges.
- Assignment (and execution) of responsibilities (security, safety, test director, asset controller, etc.) for logical range operation.
- Merging of multiple cultures and communities (terminology, process order, chain of command, Service perspective, warfare specialty, etc.).
- Exercise VV&A (are multiple objectives being accomplished, and how well? Accountability of participants and assets?
- Recognition that perfecting the "Logical Range" process is an iterative learning process.
- Utilizing foreign assets and servicing foreign customers.

RECOMMENDATIONS

The Logical Range crosses physical and Service boundaries to achieve seamless interoperability, sharing and reuse of resources. Management and cultural changes will be needed to achieve the goal of enabling the multi-site, and multi-Service Logical Range environment. The LRBPM offers common procedures and processes to support a cost and time-efficient capability to meet warfighter test and training needs.

The LRBPM provides ranges and facilities with a defined process to conduct a distributed test or training exercise. The following recommendations will help development and refinement of the LRBPM as it transitions to the test and training community:

- Promulgate the Logical Range Business Process Model for community review and discussion,
- Validate the LRBPM by following the process in a real environment,
- Compare to current facilities/ranges business processes, and determine levels of compliance to legacy systems,
- Conduct paper walk -through,

- Define, coordinate with other programs and document specific support tool requirements for the Logical Range,
- Determine if lower level of detail is needed for process viability, and
- Create a Logical Range Business Process user guide.

An *Application Concept* is the name given to a group of methods or procedures, which show how to use architecture components to solve primary customer needs. TENA is constructed to meet several primary needs that are restated below**:**

- Reducing software development and maintenance cost,
- Utilizing common instrumentation at multiple facilities,
- Responding to the increased demand for multiple-site exercises and/or exercises which cross T&E/training or live/virtual/constructive boundaries,
- Responding to the increased demand for consistency of information between facilities and across phases of the acquisition process, and
- Capturing critical data to support informed customer and management decisions about resource needs, capabilities, and investments.

Descriptions of each architectural component, such as the Technical Reference Architecture, Logical Range Business Process Model, or Product Line Approach, although they may include examples, are not intended to provide exposition of how several architecture components work together to support primary needs.

Application concepts occur in familiar environments like office computer word-processing and spreadsheet software. It is possible to gain a good understanding of the features of a word processor and a spreadsheet program as individual software tools. Most office software vendors support an additional application concept of "seamless data transfer" between programs, i.e. cutting and pasting spreadsheets into a word processor. This concept, supported by both the computer operating system and application programs, gives the user far more power than any individual application alone. The additional capabilities of the application concept are described at the operating system or application package level, not with every individual application.

TENA APPLICATION CONCEPTS

TENA defines three application concepts:

- The *Logical Range Application Concept* shows how the Object Model structure and the Logical Range Business Process Model work together to respond to the increased demand for multiple-site exercises and/or exercises which cross T&E/training or live/virtual/constructive boundaries.
- The *Systematic Reuse Application Concept* shows how the Product Line Approach and object-oriented Technical Reference Architecture reduce software development and

maintenance costs, support utilization of common instrumentation at multiple facilities, and respond to the increased demand for consistency of information between facilities.

- The *Continuous Insight Application Concept* shows how the customer focused object structure, together with the Logical Range Application Concept, allows for consistency of information across phases of the acquisition process and capturing critical data to support informed customer and management decisions about resource needs, capabilities, and investments. [Kaminski, 1995]

Together the TENA Application Concepts cover all TENA primary needs.

This Baseline TENA Application Concepts volume [TENA, 5] explains the requirements for the Logical Range and describes the Logical Range Application Concept. Expository information on other application concepts, including an explanation of how the Continuous Insight concept supports the Simulation, Test & Evaluation Process (STEP) [STEP, 1996] will be added to subsequent releases of Volume VI.

REQUIREMENT FOR THE LOGICAL RANGE

The Logical Range is one application concept for the TENA architecture. It responds to several project needs but primarily addresses integrated test and training. TENA application concepts support several higher-level requirements. These requirements are resident in the three pillars: *reduction, restructuring, and revitalization* , the basis for our long-range strategy. [Sanders, 1997]

TENA is responding to the long-range strategy with an architecture, business process and a method for deploying both—the Product Line Approach. The application concept of the Logical Range is used to demonstrate how the TENA Object Model and Business Process function to support requirements for:

- Integrated test and training,
- Re-engineered acquisition process,
- Model and simulation reuse, and
- Exercise complexity and realism.

These general statements regarding the evolving strategy for test and training can be expanded.

Integrated Test And Training

Testers and trainers often leverage each other’s facilities, but the processes are not based in any foundation architecture and consequently limited in the realizable level of integration. "Elimination of stovepiping and higher levels of integration can result in more productive and efficient utilization of range resources with no loss of effectiveness to either." [Sanders, 1997] While some integration of testing and training environments already occurs, substantial integration will require changes to range operations, infrastructure, operations and investment funding, and organizational structures. This convergence of perspectives contributes to the growing benefits of test and training integration. TENA products such as the PLA, Technical Reference Architecture and the Logical Range will provide the medium and technology to help realize this integration.

Re-Engineered Acquisition Process

The process whereby DoD acquires new weapons systems is being challenged in an unprecedented manner to become more effective and efficient. The changing world scene coupled with advances in and availability of sophisticated technologies has resulted in a reappraisal of the acquisition process. [DOD 5000.2R]

According to this reappraisal, DoD's traditional "test-fix-test" acquisition process is inherently costly and unable to quickly leverage innovative technology. "We will need a responsive research, development, and acquisition process to incorporate new technologies." [*Joint Vision 2010*] The DoD acquisition community recognizes these challenges and is in the process of re-engineering the acquisition process for major DoD weapons systems. To perform rapid simulation based prototyping for concept and design validation, a "model-test-model" . . . build process is being adopted [TEMS, 1997] [M&SMP, 1996]. The "model-test-model" process eliminates much of the time and cost of physical prototyping associated with the traditional "test-fix-test" acquisition process.

Test & Evaluation engineering processes are well suited to the model-test-model…build process [STEP, 1997] which links physical and synthetic throughout acquisition phases. The Logical Range Application Concept links the physical and synthetic. It supports the Continuous Insight Application Concept that is a method for implementing STEP across the test and training domains.

Model And Simulation Reuse

The Defense Advanced Research Projects Agency (DARPA) estimates that typically 75 percent of the cost of developing a new simulation system goes into building the simulation infrastructure, while only 25 percent is used to develop components specific to the purpose of the simulation. Duplication of effort has mitigated any of the potential cost effectiveness promised by M&S.

A synthetic battlespace using a TENA Logical Range is envisioned as the technical and efficient response to this shortfall and, in the future, testers/trainers will rely on a combination of physical and synthetic resources. The key to any major weapon system acquisition has always been testing and evaluation in the correct operational environment. Similarly, the training community advocates "train as you fight, fight as you train" which can only be economically realized through application of M&S. The Logical Range, modeled on the functionality of current instrumented ranges, will allow any user to identify requirements and satisfy them through the dynamic networking of physical and synthetic assets.

Exercise Complexity And Realism

There is strong need in DoD to provide an environment or battlespace capable of meeting complex scenario requirements and achieving more realism. DoD is burdened with mission oriented, stove-piped systems and requirements at a time when a potential solution is available to seamlessly and synergistically integrate across domains and systems. Most efforts, to date, have not been supported by a strong architectural foundation that promotes rapid deployment of exercise scenarios.

CONCEPTUAL VIEW OF THE LOGICAL RANGE

With the concept of the Logical Range, existing physical ranges can now be expanded by connecting other test and training ranges to form a larger range complex. Each of these configurations, using local and/or remote resources, is a Logical Range.

In the Conceptual View of the Logical Range, shown in Figure 9, an exercise is supported through dynamic composition of assets assembled from physical ranges, hardware-in-the-loop (HITL) facilities, RDT&E labs, Smart Product Models, or any other site where a modeled, prototype, or production copy of an entity in the battlespace exists. The assembled combination of components is uniquely defined to perform a specific test or training exercise. Each site is private, and is managed and supported in accordance with the principles of the sponsoring organization.

A resource can be physical or virtual and can represent measurement systems, environments, personnel, equipment or any grouping required to meet exercise requirements. It is very much like a typical test or training Open Air Range (OAR), except that it may use resources from multiple physical ranges and/or other cooperating test and training resources.

Figure 9 Conceptual View of the Logical Range

LOGICAL RANGE APPLICATION CONCEPT DESCRIPTION

The Logical Range Business Process Model and the TENA Object Model contribute to the Logical Range by providing a definition of standard processes and object classes respectively. Detailed explanations of the OM and LRBPM are found in Volume IV and V of the TENA Baseline Report. A walk-through example for a Logical Range test illustrates the Logical Range application concept. The Logical Range provides a variety of benefits in facilitating distributed test and training exercises that are identified in volume VI.

Most of the interaction among Logical Range objects is embodied in tools such as a browser. These tools enable add-on applications (e.g. sort, display, schedule, etc.) that will be required to support Logical Range composition and execution. This document assumes the existence of such supporting tools.

A notional example of a scenario is a customer who has the objective of evaluating the drive train of a field-ready tank for traction and durability. The customer wishes to compare different scenarios in order to determine a cost-efficient alternative to conduct his test. He will consider any combination of virtual, constructive and real scenarios that will minimize test runs, thus minimizing costs. The following scenario variants are examined in Volume VI:

- Simulated tank on a simulated hill,
- Real tank on a simulated hill,
- Real tank on a tilt table,
- Real tank on a tilt table under environmentally controlled conditions
- Real tank on a real hill

The Integrated Validation and Verification (IV&V) Plan [TENA, 6] addresses TENA verification and validation throughout the life cycle. It covers the conceptual design, known as the TENA Technical Reference Architecture (TRA), the prototypes, and the installed system capability. These activities are divided into phases as follows:

- Phase **I -** Verification of technical architecture against requirements for the logical range. This will be performed analytically.
- Phase **II -** Verification of system architectures against requirements for range instances. This will be performed through prototypes to test architectural elements.
- Phase **III -** Validation of implementation against range operator expectations and actual test plans. This will include integration and acceptance testing.
- Phase **IV - I**nstallation of the operational system.

The schedule for these phases will span the development and Initial Operational Capability (IOC) testing of systems constructed using TENA products.

GOALS OF THE IV&V PLAN

The IV&Vplan is written for any person interested in the verification and validation of TENA products. It does not contain detailed engineering procedures.

The IV&V plan supports the Product-Line Approach presented in Volume II and the Transition Plan presented in Volume VIII.

This plan provides a review of the goals and foundations for the TENA IV&V process and a discussion of each phase. The process is a tailored version of the DoD recommended approach to V&V. A preliminary schedule is included. Appendix C of the IV&V Plan contains several scenarios that will be used later for validation of certain aspects of the TENA project. The goals of the V&V activity are to:

- *Analyze the architecture for specific attributes. This will include architecture assessment by creating scenarios for development and use of the architecture with respect to specific characteristics and requirements. The analysis will measure the ability of the architecture to meet these attributes.*

- *Verify effectiveness of architecture elements. This goal will be satisfied by building prototypes that use portions of the architecture to perform realistic system functions.*

- *Validate ability of the architecture to support operational systems. The architecture and components will be used to build actual systems. Validation will be met upon successful acceptance testing of systems.*

TENA V&V will be integrated with product development.

FOUNDATIONS FOR THE TENA V&V PROCESS

The DoD [VV&A, 1995] has established a Validation, Verification and Accreditation (VV&A) Technical Support Team to develop guidelines for VV&A practices within DoD. We have tailored these guidelines to serve as a basis for VV&A of the TENA development products. The following list provides the generic process for V&V defined by the DoD team and tailored for TENA purposes. These steps will be grouped into specific phases of the TENA process previously mentioned and as shown in bold text below.

1. *Determine V&V Requirements - This covers determination of the level of effort, techniques, V&V agent, etc. This Integrated V&V Plan will evolve to include all the TENA V&V requirements.* ***{TENA IV&V Process-Phase I}***

2. *Initiate V&V Planning - V&V tasks should mirror development. They should proceed in parallel with the development and refinement of the TENA architecture, with key development milestones driving the execution of V&V tasks. Task planning will be the first step of V&V for TENA and will collect and review development requirements. It will identify necessary tools and resources. The initial steps provided in this plan are rather general; as the TENA capability evolves, these plans will become more detailed.* ***{TENA IV&V Process-Phase I}***

3. *V&V the Conceptual Model - For TENA, the conceptual model is the Technical Reference Architecture (TRA) and its associated Logical Range Business Process Model (LRBPM). Verification of the conceptual model only covers analysis and assessment of the TRA.*

Step 3 will generally follow the Software Architecture Assessment Method (SAAM) [Clem, 1996] shown below. TENA has already made progress on several SAAM steps and that progress is shown in italics. The major steps of the SAAM method are ***{TENA IV&V Process-Phase I}****:*

- ***Gather stakeholders*** **- The architecture assessment will include input from across the range community. This step identifies categories of stakeholders and makes sure individuals from each category will participate.** ***The TENA Transition Plan includes a list of known stakeholders.***

- ***Establish architecture goals*** **- The stakeholders provide their needs for the system in terms of quality factors such as maintainability, ease of use, and performance, as much as for functional capabilities.** ***TENA Requirements, Volume III provides a baseline set of stakeholder needs.***

- ***Develop scenarios to test for goal compliance*** **- The stakeholders express their interactions with the system in terms of scenarios. These may include specific use interactions.** ***A set of candidate scenarios has been developed by the TENA Project Team and can be found in Appendix C to the IV&V Plan.***

- ***Apply scenarios against the architecture*** **- The scenarios are exercised by testing their application within the architecture. For example, if a scenario requires the ability to replace one sensor with another during an exercise, ask questions such as: can the architecture support this replacement? If not, how much of the architecture must be changed to accommodate the replacement?** ***This activity is planned for FY98. Selection of tools to support this analysis is in progress. Initial assessment of Object modeling tools is found in Appendix D of the IV&V Plan.***

- ***Document the scenarios*** **- Note those that are supported through the architecture, or those that will require architecture changes.**

- ***Report results*** **- Produce an architecture assessment report that describes the architecture, the scenarios, and the results of the scenario- based evaluation.**

1. *V&V the design - For TENA, this step will look at a system architecture, built using the elements of the TRA. The goal is to verify the ability of the architecture to define T&E information needs, operations, and connectivity. This step usually focuses on high-risk areas of the design.* ***{TENA IV&V Process-Phase II}***

2. *V&V the implementation - This step will also look at system architecture once the TRA and at least one TENA application are completely implemented.* ***{TENA IV&V Process-Phase II}***

3. *V&V the application - This step will be performed at a facility where an actual exercise will use the TENA capability to construct an instance of a logical range.* ***{TENA IV&V Process-Phase III}***

4. *Perform acceptability testing - For TENA, this step will review the information collected during the overall V&V process to assure usability for constructing a logical range using TENA products. This step will determine if TENA can support real-time operational events on ranges and at facilities.* ***{TENA IV&V Process-Phase IV}***

SCENARIOS FOR TENA VALIDATION & VERIFICATION

Eight candidate scenarios have been developed by the TENA Project Team for use in verification and validation of the Technical Reference Architecture, Logical Range Business Process Model, and other products of the project. These scenarios are designed to encompass a wide range of activities, forces/participants, and missions. Table 1 is a summary matrix of the scenarios that are found in Appendix C of the IV&V Plan. An example scenario is presented in Appendix C to this Management Overview.

Table 1. TENA Scenario Summary Matrix

USA VPG	**JADS**	**JCSAR**	**Roving Sands**	**JTCTS**	**AF/NAVY West Range**	**AAAV**
1	2	3	4	5	6	7
Natnl Trng Cntr	AF Devlp Test Ctr	USCENTCOM	USCENTCOM	JTF	AF Flight Test Center	National Trng Cntr
TECOM	ADS TCAC	JCSAR JTF	FORSCOM	Carrier Battle Group	Edwards Test Range	MARCORSYSCOM
WSMR			USACOM	Amphib Ready Group	China Lake Test Range	USMC Air-Grnd TF
RTTC			TECOM	Maritime PrePos Sq	Nellis Test Range	TECOM
EPG			JITC	Marine Expedn Bgde	Point Mugu Test Range	Camp Pendleton
			JIADS	Marine Air Wing	Yuma Proving Grounds	Point Mugu Test Rng
			JPOC	Marine Air Cntgy Force	WSMR	Aberdeen Prvng Grnds
			BMDO	Army Abne Corps	CTFs	Nellis AFB
			WSMR	AF Composite Wing		
			EPG	AF SOF		
			✓	✓	✓	✓
✓			✓	✓		✓
	✓		✓	✓	✓	✓
			✓	✓		✓
	✓	✓	✓	✓	✓	✓
			✓			

✓	✓	✓	✓		✓	✓
	✓		✓		✓	✓
✓		✓	✓			
✓		✓	✓	✓		
✓	✓		✓	✓	✓	✓

Widespread acceptance of the TENA project by all of its users and customers is necessary to ensure project success. The TENA user community is extremely broad in scope, including acquisition program managers in traditional T&E roles, operational testers, test ranges and facilities, operational Service/joint commands, industry and academia. The TENA Project team has established close liaison with the Range Commanders Council (RCC), Common Test and Training Range Architecture (CTTRA) Group, and the Test and Evaluation Reliance Investment Board (TERIB). Liaison with these groups will not only produce a better set of requirements, but will also engender the relationships that will help with the acceptance and transition of TENA to the Services.

TENA TRANSITION PROCESS

TENA is an architecture that will require additional attention and upgrade after delivery to be truly effective. TENA is applicable to both the test and training community open-air ranges, but it also impacts other non-traditional test and training programs such as modeling and simulation (M&S). TENA cuts across all Services and several federal agencies. Much of TENA is grounded in the technology and architecture advances that are driven by industry telecommunications and computing segments. The different nature of the TENA project is significant enough to represent a requirement for a centralized management methodology designed to support rapid upgrade of software architectures, while at the same time allowing for "bottoms-up" market-driven initiatives to thrive. That methodology is the Product-Line Approach, which is presented in Volume II of the Baseline Project Report. The TENA Transition process is based upon the PLA.

The TENA Transition approach consists of four phases:

- Conduct Product-Line Approach Analysis,
- Conduct Logical Range Pilot Effort for Concept Exploration,
- Determine Product Line Organization, and
- Establish Product-Line Approach.

Product-Line Approach Analysis

The PLA Analysis is a six-month project that takes a critical look at how to apply the PLA to test and training ranges and facilities. This phase will evaluate problems and concerns with existing ranges, establish why product lines are important, identify potential reuse opportunities, evaluate the range management organization, and determine critical business and economic factors. The output of this phase will be a product-line practice framework for test and training resources and ranges and a draft PLA organization.

Logical Range Pilot Effort For Concept Exploration

The Logical Range pilot effort will be a concept exploration applying a product-line framework to a selected candidate OAR. The second phase will select some TENA architecture critical features and applications and evaluate problems that might be encountered implementing the PLA. The effort will also concentrate on issues related to developing the system architecture from the Technical Reference Architecture. The end result will be to reduce the risk of implementing a PLA for test and training resources and ranges. An output of the pilot effort will be an evolution strategy and draft product group/product support group management strategies.

Identify Test And Training Product-Line Organizations

Using criteria from the transition plan or other criteria that may be developed in the future, recommendations will be determined for product-line organizations to support the TENA architecture. There are four groups within a product-line organization that may be applied to resources and ranges.

Responsibilities of the product-line organizations are found in the Product-Line Approach, Volume II, Table 2 of the Baseline Project Report and can also be found in this Management Overview in the section titled Product-Line Approach.

Establish Product-Line Approach

After successful evaluation of the TENA architecture and completed verification and validation testing, an implementation strategy that will consist of the establishment of the Product-Line Approach to supporting test and training resources and ranges will be developed. This strategy will address:

- Business and economic factors,
- Technical factors,
- Process factors,
- Organizational factors,
- Role of Management, and
- Core competencies and skills

LIFE-CYCLE SUPPORTABILITY ISSUES

Life cycle supportability issues must be addressed for TENA to survive and become the living architecture for ranges into the next century. Life cycle supportability issues include TENA compliance, TENA expertise, transition, and software deployment and support. Additional life cycle supportability issues, as well as, cultural and technical issues will be defined during the coming months through discussion with the TENA stakeholders. See Volume VIII, Appendix D for a discussion about TENA stakeholders. As the Technical Reference Architecture is used to build multiple system architectures, one issue that is both cultural and technical that will be addressed is TENA compliance. Compliance can be applied to both a facility within the TENA Enterprise and individual components or assets. See Volume VIII, Transition Plan [TENA, 7] for an in-depth discussion of both compliance levels.

TENA Expertise

After the TENA architecture is developed, it will require periodic updates as new standards and protocols are developed in both government and industry. Provisions should be made to preserve the TENA architecture core expertise. This preservation may become the essence of the TENA Architecture Group as the TENA project is transitioned from the existing tri-Service IPT to some other form or organization.

The architecture is critical to the success of the Product-Line Approach. Key product line decisions are made during the process of developing or selecting the product line architecture. These include:

- Naming the critical issues in product line development (product line selection and inclusion, handling commonalties and differences, security, interoperability, reliability in product delivery),
- Determining how the product line support interoperability/component integration issues (e.g., the High Level Architecture (HLA)),
- Compliance and levels of compliance,
- Legacy systems,
- New development,
- Determining plans for change/evolution management within the product line,
- Naming key quality factors (for example, performance, security, dependability) that are essential for the product line,
- Determining how the product line will take advantage of COTS/software sharing, and
- Establishing how systems will be built (operational, system, and technical architectures).

Product Line Approach Transition Issues

By using the product-line systems approach, organizations will deploy systems faster, at a lower cost, and with fewer Government and industry resources. Systems will be even more reliable because they will use common components that will have high reliability and proven performance characteristics. Training will be improved since common components will reduce the amount of training currently needed when transitioning between command and control systems. More commercial components will be available because industry will identify a larger market for their products when used across similar systems.

Upgrades of components will also be promoted as industry recognizes a new market for their enhanced products.

The successful implementation of a product-line systems approach presents challenges and barriers that are significant but surmountable. These include

- *Cultural* ***- Product-line strategies mean organizations and managers have less direct control over their product developments and increased dependency on other organizations to understand their requirements and provide acceptable solutions. Giving up this control and the necessary dollars to support product-line technology and application development may be difficult.***

- ***Strategic planning - Product-line planning is not only a management process that links related systems. The Range Development Organization must consider the long-term needs of users and the ability to build products for those users. They must take an enterprise-wide look at existing and planned products and look several years into the future in planning for product-lines. The future year development plans should focus attention on product-lines as the means to satisfy the plan.***

- ***Need for tradeoffs - The product-line approach presents a tradeoff for the user between "build me the exact system I want" and "build me a system almost like what I want using the product-line, saving on costs and time."***

- ***Resource ownership - Who will "own" the product-line components? How will they be funded? These issues require transitioning from program- focused acquisition organizations and budgets to more commercial-like product organizations and budgets.***

- ***Recognition and reward -The current acquisition system focuses on recognition and rewards for personnel on delivered systems. Use of product-line strategies also necessitates a shift to rewarding and advancing personnel for broadening the utility of products and facilitating their use within and across product-lines.***

- ***User interface - Users will experience close ties to the development organization within the Product Development Groups. They should experience greater responsiveness through improved needs definition, refinement, and early demonstration. However, operational users must adjust to having more than the program managers as their dependency links to successful system upgrades or developments. This should not be difficult since users today are regularly dependent on a variety of sources for successful systems deliveries.***

- ***Effects of technological change - The transition to a Product-Line approach will mean significant changes in our current way of doing***

business. We must plan for the effects this will have on the individuals who must carry out the transition and also on those who will be operating under the new approach.

Software Deployment And Support

Ten years ago, most ranges developed their own tracking, range safety, display, and analysis software. As a result, much of the software was specific to the individual range or range subdivision, even when the functionality did not differ significantly between sites. Hardware-dependent data formats characterized the software implementations at each range. Full-time software personnel were stationed on site to support each implementation.

This software development and support system arose for several reasons. Software was added to the range as an adjunct to the hardware that performed the range functions and was not considered separately. Software was cheaper than hardware and, therefore, not considered a cost driver. No connectivity existed between the ranges, so a requirement for a common approach to software was not identified.

These conditions have changed. The cost of software, relative to hardware, has increased dramatically. At the same time, the dependency of software on its hardware platform has been reduced through the introduction of third- and fourth-generation high-level languages and vendor competition.

Centralized software development, conducted at laboratories remote from the range, has become both possible and desirable. One issue that surfaces when software is developed at a site other than the site where it will be used is the method of delivery. There are four basic methods for software deployment and support:

- Customized software delivery,
- Commercial market software delivery,
- Distributed software download, and
- Just-in-time software distribution.

For a discussion of the merits and disadvantages of each method, please see Appendix C of the Transition Plan. The TENA architecture will support all of these methods.

TRANSITION MANAGEMENT AND OVERSIGHT

Transition management and oversight is the responsibility of the TENA Project Director in conjunction with the Sponsor and user community. The TENA Architecture will make a difference to the way business is done in the test and training communities. However, for lasting and significant progress to be achieved the management and oversight of the transition of TENA must be through establishment of the Product-Line Approach. This is fundamental to the ability of DoD to achieve goals and objectives enumerated at the highest levels of the organization. The benefits of PLA can be seen in the paragraphs below.

Significant discussion and review will occur over the next few years as the DoD and Services work towards implementation of a methodology to guarantee fully tested and capable cost-effective systems reach the hands of our warfighters. The TENA Project Team will undoubtedly learn much as those discussions happen and the Transition Plan will be updated as significant concerns and issues are discovered.

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Volume IX of the TENA Report contains the detailed Glossary of Terms and Definitions. This volume should be available when reading this Management Overview or any of the technical volumes.

The test community has often been criticized for not using a standard lexicon. The TENA Project Team uses the DoD standard reference to terms and definitions, JCS Pub 1-02. Volume IX of the TENA Baseline Project Report is a Glossary of Terms and Definitions. It is based upon Joint Pub 1-02 and the following::

- Simulation Test and Evaluation Process (STEP) Guidelines
- Navy Test and Evaluation Modeling and Simulation (TEMS) Master Plan Glossary
- Joint SIMulation System (JSIMS (ORD)) Architecture Glossary
- High Level Architecture (HLA) Glossary
- Defense Modeling and Simulation (DMSO) Modeling and Simulation Glossary
- Defense Information Infrastructure-Common Operating Environment (DII-COE) Architecture
- Joint Technical Architecture
- TENA Project Team

In the glossary we indicate by [ ] where the particular term or definition originates. In some cases terms may be original to the TENA project and those appear without a bracket.

Volume X contains various reports and documents which are related to the overall project. These are research efforts, procedural and documentation guides and other studies which support the development of the project or project deliverables. A listing of the contents of volume X follows:

- Test and Training ENabling Architecture (TENA) Range Visit Information and Points of Contact (POC)
- Test and Training Range Software Maintenance Survey (MITRE)
- Simulation, Test, and Evaluation Process (STEP) Guideline
- Software Engineering Institute Report CMU/SEI-96-TR-016-A Case Study in Successful Product Line Development
- TENA Work Breakdown and Tasking Description (Pilot Phase)
- Common Test and Training Range Architecture (CTTRA) Program Requirements Matrix
- Edwards AFB-China Lake ATM Test and Demonstration Report

BoOD Board of Operating Directors

BPR Business Process Reengineering

C4I Command, Control, Communications, Computers & Intelligence

CDAPS Common Display and Analysis Program

CINC Commander-in-Chief

CJCS Chairman Joint Chiefs of Staff

CNO Chief of Naval Operations

COE Common Operating Environment

COTS Commercial-off-the-Shelf

CTEIP Central Test and Evaluation Investment Program

CTTRA Common Test and Training Range Architecture

DII Defense Information Infrastructure

DISA Defense Information Systems Agency

DMSO Defense Modeling and Simulation Office

DoD Department of Defense

DTTSG Defense Test and Training Steering Group

DTEC Defense T&E Complex

HITL Hardware-in-the-Loop

HLA High Level Architecture

HWIL Hardware-in-the-Loop

ISTF Installed System Test Facility

IT-21 Information Technology--Twenty-First Century

IV&V Integrated Validation and Verification

JCS Joint Chiefs of Staff

JIM Joint Improvement and Modernization

JMASS Joint Modeling and Simulation System

JPO(T&E) Joint Project Office (Test and Evaluation)

JRRC Joint Regional Range Complex

JSIMS Joint Simulation System

JTA Joint Technical Architecture

JTTRR Joint Test and Training Range Roadmap

JWARS Joint Warfare Simulation

LFT&E Live Fire Test and Evaluation

M&SMP Modeling and Simulation Master Plan

MAIS Major Automated Information Systems

MDAP Major Defense Acquisition Programs

MRTFB Major Range & Test Facility Base

OM Object Model

OSD Office of the Secretary of Defense

OT&E Operational Test and Evaluation

PDUSD(A&T) Principal Deputy Undersecretary of Defense (Acquisition & Technology

PE Program Element

PLA Product-Line Approach

RCC Range Commanders Council

RDT&E Research, Development, Test & Evaluation

SAAM Software Architecture Analysis Method

SECDEF Secretary of Defense

SEI Software Engineering Institute

SETI Synthetic Environment Training Initiative

SISO Simulation Interoperability Standards Organization

STEP Simulation, Test and Evaluation Process

SWIL Software-in-the-Loop

T&E Test and Evaluation

TEMS Test & Evaluation Modeling & Simulation

TENA Test and Training ENabling Architecture

TERC Test and Evaluation Resource Committee

TERIB Test and Evaluation Reliance Investment Board

TFR Test Facility Resources

TIRIC Training Instrumentation Resource Investment Committee

TIS Test Investment Strategy

TRMP Test Resource Master Plan

USD(A&T) Under Secretary of Defense (Acquisition & Technology)

VTTR Virtual Test and Training Range

WSMR White Sands Missile Range

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Scenario 6

Mission Statement

Synopsis:

Scenario 6 is an Air Force/Navy scenario designed to test various aircraft and guided weapons across multiple Western ranges. The scenario comprises: (1) flying a test aircraft from Edwards AFB to a remote Open Air Range (OAR); (2) testing the aircraft's performance, flight qualities, or weapons system; (3) downlinking test data from the aircraft to a ground-based communication center; (4) transmitting the data back to Edwards AFB; (5) processing and displaying test data in near real-time; and (6) evaluating the performance of the System Under Test (SUT) during the mission and moving on to additional tests.

Test Objective

The purpose of the test is to evaluate the performance of an aircraft or weapon system in a cost-effective manner, using multiple range facilities over a distributed system. Modeling and Simulation techniques can also be used to link the live aircraft to hardware-in-the-loop (HITL) or installed system test facilities (ISTF) at Edwards AFB or remote facilities.

Test objectives include: 1) Assess the performance of the aircraft or weapon system through open air testing; 2) process, display, and evaluate test data during the mission; and 3) assess efficiency of sharing resources that are connected over a distributed system.

Global Positioning System (GPS)-aided Time-Space-Position Information (TSPI), telemetry (TM) data, voice, and video are down linked from the aircraft and passed to the mission control center at the remote range. The remote range gathers the data from the aircraft and range, multiplexes and formats the data to an inter-range standard, and then transmits the data over existing communication links. At Edwards AFB, the Ridley Mission Control Center (RMCC) receives, processes, and displays the data in real time. The data is also recorded for post-processing and later retrieval. This scenario is applicable to several Combined Test Forces (CTFs) operating at Edwards AFB including the F-16, F-22, B-1, B-52, X-33 and the Joint Strike Fighter.

Implementation

Figure 10. Strategic Scenario

Figure 1 summarizes the strategic test scenario. The test director initiates the test at Edwards AFB, CA and schedules resources at remote ranges. The test aircraft flies to the needed range resource(s) and the test mission is performed. The aircraft remains in constant contact with the test conductors at Edwards via communication links. The strategic scenario may be broken down into three detailed scenarios: 1) a Land Range scenario where a B-1 or B-52 drops a Joint Direct Attack Munitions (JDAM) at the Naval Air Warfare Center (NAWC) – Weapons Prototype (WP) Land Range; 2) a Sea Range Scenario where an F-16 or F-22 conducts testing over the Pacific Ocean; or 3) an Echo Range scenario where an F-16 performs Electronic Warfare testing at the NAWC-WP Echo Range.

Figure 2. Tactical Situation – Land Range Scenario

Figure 2 depicts the Land Range Scenario tactical situation. This exercise combines assets located at both the Edwards Air Force Base and China Lake test ranges.

Edwards Air Force Base is located on the western edge of the Mojave Desert about 100 miles northeast of Los Angeles, 90 miles northwest of San Bernardino and 80 miles southeast of Bakersfield. It is the home of the Air Force Flight Test Center (AFFTC), where the Air Force has tested nearly every aircraft in its inventory. The AFFTC carries out flight test and evaluation programs for Air Force units, the Department of Defense, NASA and other governmental agencies.

The NAWC Weapons Division (NAWCWPNS) China Lake is located approximately 60 miles north of Edwards Air Force Base, encompasses over 1.1 million acres, and lies under some 17,000 square miles of joint-service restricted airspace. China Lake is home to approximately 4,000 civilian employees and about 1,000 military personnel (including tenant Operation Test and Evaluation Force squadron VX-9) and is supported by over 1,500 contractor employees. China Lake programs include Research Development Test and Evaluation (RDT&E) and support for air-to-air and air-to-surface missiles, fuses for a wide variety of surface-to-air and air-to-air missiles and free-fall weapons, antiradiation-missile programs, parachute systems and subsystems for aircrews and equipment, avionics hardware and software and total-combat-system operational flight programs (OFPs) for most Navy fighter and attack aircraft, and tactical electronic-warfare and countermeasures systems.

The Land Range scenario commences as a B-1 test aircraft flies from Edwards Air Force Base to the NAWC-WP Land Range at China Lake. Capable of flying at high subsonic speeds at extremely low altitudes, the B-1 relies upon an automatic terrain-following system, electronic jamming equipment, infrared countermeasures and other sophisticated systems to detect, evade and defeat enemy defenses. The B-1 can carry conventional and nuclear bombs as well as short-range attack and air-launched cruise missiles.

Time Space Position Information (TSPI), Telemetry, and Voice data are downlinked from the aircraft to the China Lake Land Range. Aircraft data and range video are then transmitted back to the Edwards Ridley Mission Control Center (RMCC) via existing microwave links.

The B-1 then performs its weapons test and drops the Joint Direct Attack Munition (JDAM) on the range. JDAM is a joint Air Force/Navy program designed to provide current fighter and bomber aircraft the capability to accurately and precisely attack fixed or relocatable land and maritime targets, under adverse weather conditions and from medium to high altitudes.

Test data is processed and displayed at Edwards in near real-time. The RMCC coordinates the remote test and moves on with further tests if the initial test is determined to be completed or not attainable -- saving both time and money.

Figure 3. Tactical Situation – Sea Range Scenario

Figure 3 depicts the Sea Range Scenario tactical situation. This exercise combines assets located at both the Edwards Air Force Base and the Point Mugu NAWC-WP test ranges.

Point Mugu Naval Air Station is located approximately 10 miles south of Oxnard, CA. As a component of the NAWCWPNS, it serves as the Navy's principal weapon system test and evaluation activity, providing in-service engineering support to naval weapon systems. Point Mugu NAS has 36,000 square miles of West Coast air and sea ranges in support of both national and international test programs.

The Sea Range scenario commences as a test aircraft – either an F-22 or F-16 -- flies from Edwards AFB to the NAWC-WP Sea Range at Point Mugu. TSPI, Telemetry, and Voice data are downlinked from the aircraft to range facilities at either San Nicholas Island or Point Mugu NAS. Aircraft data and range video are then transmitted back to the Edwards' RMCC via existing microwave and fiber optic links.

The test aircraft performs its test using sea range assets such as arial targets and ships, or it participates in a fleet training exercise conducted on the sea range. Test data are processed and displayed at Edwards AFB in near real-time. The RMCC coordinates the remote test and moves on with further tests if the initial test is determined to be completed or not attainable -- saving both time and money.

Figure 4. Tactical Situation – Echo Range Scenario

Figure 4 depicts the China Lake Echo Range Scenario tactical situation. This exercise combines assets located at both the Edwards Air Force Base and China Lake Echo Range test ranges.

The mission of the Electronic Combat Range (Echo Range/ECR), which was established in 1968 to support the Vietnam conflict, is to develop, operate, maintain, and continuously improve a free-space laboratory that provides engineering support, Developmental Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E)), analysis, training, and electronic warfare resources. The Range is used by developers, integrators, testers, and users of systems and technologies that counter or penetrate air defenses. The ECR is made up of sea and land threat-system sites, reference systems, a computer/operations center, the Slate Range Facility (SRF) for static ground testing and test monitoring, and engineering/logistics-support offices.

The Echo Range scenario commences as a test aircraft flies from Edwards AFB to the NAWC-WP Echo Range at China Lake. TSPI, Telemetry and Voice data are downlinked from the aircraft to the Land Range. Aircraft data and range video are then transmitted back to the Edwards' RMCC via existing microwave links.

The test aircraft performs its electronic countermeasures testing on the range. Test data are processed and displayed at Edwards AFB in near real-time. The RMCC coordinates the remote test and moves on with further tests if the initial test is determined to be completed or not attainable -- saving both time and money.

Execution

Figure 5. Layer 1 Event Trace.

Figure 5 is an Object Modeling Technique (OMT) event trace diagram depicting the first layer of Scenario 6.

The customer plans the exercise.

The customer assesses range capabilities and determines the resources required to conduct the exercise.

The customer schedules logical range resources to conduct the exercise.

The exercise is conducted over the logical range.

Test personnel collect data and process results.

Results are presented to the customer.

Figure 6. Layer 1 Event Trace.

Figure 6 is an Object Modeling Technique (OMT) event trace diagram that depicts the generic tactical exercise associated with Scenario 6.

The test conductor initiates the test using the communications asset.

The RMCC uses the communications asset to launch the system under test.

The system under test transmits test data to the appropriate receiver or sensor.

The receiver or sensor passes the test data to the RMCC using the communications asset.

The RMCC processes the data using the computing asset.

The computing asset p[asses the processed data to the presentation asset.

The presentation asset presents the data to the RMCC.

The system user performs additional tests on systems under test and receives processed data from the presentation asset.

PURPOSE:

This paper presents the conclusions of the TENA Software Reuse Cost Analysis. It was conducted by the TENA Project Office to show the impact that systematic reuse of software, as practiced in the Product Line Approach (PLA), could have in the development and maintenance cost of test and training systems software.

The Software Reuse Cost Analysis depends on understanding the types, quantity, and costs of software currently supported on test and training ranges and facilities. TENA sponsored an independent activity by MITRE Corporation to gather this data [TENA,1]. The surveys which were submitted are available in [TENA,2].

METHODOLOGY:

The TENA team used a twofold approach that included the distribution of a questionnaire and visits by TENA team members who have extensive experience developing multiple range systems. The information gathered through the questionnaire and visits was analyzed to develop valid parameters that were used to model the cost of developing software for systematic reuse.

The following TENA member ranges were provided the questionnaire and have provided some level of data: Electronic Proving Ground (EPG), Naval Air Warfare Center-Weapons (NAWC-WPNS) Point Mugu, Air Force Flight Test Center (AFFTC)-Edwards Air Force Base (AFB), Atlantic Fleet Weapons Training Facility (AFWTF), and Atlantic Undersea Test and Evaluation Center (AUTEC). The survey was also provided to three additional MRTFB locations, but no data has been provided by these ranges to-date. A site visit to the Aberdeen Proving Grounds-Aberdeen Test Center (APG-ATC) was conducted where additional software data was collected. Also, software metric data provided from a survey performed by the CTEIP Common Display, Analysis and Processing Software (CDAPS) project, included information from White Sands Missile Range (WSMR), NAWC-Patuxent (PAX) River, and Arnold Engineering Development Center.

The survey requested number of Software Lines of Code (SLOC) from each range and the resulting data is presented in Table 1. The SLOC range from a low of 19,000 to over 2.4 million lines. This resulted from some ranges counting only real-time systems while others counted software used in scheduling, data analysis, and Management of Information Systems. Using this information we present a low-end and high-end analysis and compute the cost of developing and maintaining software on ranges. The low-end analysis assumes that an average range’s SLOC is 500,000 lines of code while the high end assumes 2,000,000 SLOC. The primary real-time systems (of which there may be more than one at a facility) need an average of 500,000 lines of code to perform routine data acquisition, processing, filtering, display, archiving, and operational control functions. This number was used as the "low range" in deriving a reasonable range in our preliminary reuse cost estimates. The study presents conclusions for development costs in a non-reuse environment and a reuse environment. There are required development costs associated when an activity decides to develop in a reuse environment. These costs normally range about 140% of the total development costs. Since reuse heavily impacts the cost of maintaining software, we also examined the maintenance costs in both the high-end and low-end cases.

Table 1 Software Lines of Code (SLOC) at Test and Training Ranges

Range	**Lines of Code**
APG-ATC	413,000
EPG	19,000
NAWC-WPNS Pt. Mugu	237,000
AFFTC	913,500
AFWTF	622,000
AUTEC	2,400,000
WSMR	420,600
NAWC-Pax River	279,000

Arnold Engineering Center	700,000
Total	6,004,100

Software cost estimation models and software reuse economics include multiple methods and techniques. These range from simple parametric models to those which capture measures of the complexity of a system to predict its development and/or maintenance costs. The complexity of a model does not necessarily increase its accuracy.

The TENA team used a simple model, described below, to derive a bracketed estimate of the expected cost benefits of applying systematic software reuse techniques (practiced by the PLA) to the development and maintenance of test and training range and resources software. This model has been used by the US Army Reuse Center and others to generate Raw Order of Magnitude (ROM) estimates.

The cost of developing software in a Non Reusable Environment (**$Cost_{NRE}$**) is simply:

$$\mathbf{Cost_{NRE} = SLOC * C_D \{1\}}$$

where:

SLOC = Software Lines of Code

C_D = Development Cost Per Line of Code

The cost of developing software using a systematic reuse approach ($COST_R$) is:

$$\mathbf{COST_R = SLOC * C_{LC} * DC_R * TC_R \{2\}}$$

where:

$COST_R$ = Cost in Reuse Environment

DC_R = Factor for the Additional Development Cost of Reusable Software

TC_R = Factor of the Additional Test Cost of Reusable Software

The annual cost of maintaining code in a non-reuse environment is:

$$AMCost_{NRE} = (SLOC * C_M) * P_M \{3\}$$

where:

$AMCost_{NRE}$ = Annual Maintenance Cost in Non-Reuse Environment

C_M = Maintenance Cost per Line of Code

P_M = Annual Percentage of SLOC Maintained

These simple equations were used to compare the cost of developing and maintaining software without adopting a systematic reuse approach to the cost using the PLA, with the number of new systems being the independent variable. We also computed the cumulative effect of software development and maintenance over a ten year period. Finally, we compared development, maintenance, and cumulative cost of both techniques to derive an expected cost benefit.

ASSUMPTIONS:

The above steps were performed for both a low-reasonable and high-reasonable estimate using very conservative assumptions. The values used for key factors and the range of values we have seen in similar efforts are summarized below:

FACTOR OUR VALUE TYPICAL RANGE

- Development Cost/Line of Code = $75.00 [$50.00-$150.00]
- Maintenance Cost/Line of Code = $75.00 [$74.00-$200.00]
- Factor for the Additional

  Development Cost of Reusable Software = 1.5 [.9-1.3]
- Factor for the Additional Test

  Cost of Reusable Software = 1.4 [.9-1.4]
- Maintenance = 10%/Year of Deployed Software [5-20%]
- Number of Participating Systems = 10 Nominal [1-50]
- Time Line = 10 Years [5-15]
- Reusable software per facility = 70% [70-95%]

- It usually cost more to develop a reusable component. The economics show that after a certain number of systems are deployed there is a point when your investment in reusable components starts to pay off. The break-even point will vary based on the size of system, percent reused, and development cost factors.
- Additionally, each deployed system has a different maintenance cost profile. Using the Product Line Approach only the facility-specific, non-reusable code maintenance cost must be born solely by the facility. The reusable components are maintained primarily by the Product Line Organization (which may be institutional funds or shared expenses).

ANALYSIS

Software Development and Maintenance with Current Environment

Following the above assumptions, the cost for developing and maintaining software in a non-reuse environment for a single and various multiples of systems is shown in the table below:

Table 2 Software Development/Maintenance in a Non-Reuse Enviornment over 10 years

	500,000 SLOC			2,000,000 SLOC		
No. Systems	$COST_{NRE}$	$AMCOST_{NRE}$	CUMM $AMCOST_{NRE}$	$COST_{NRE}$	$AMCOST_{NRE}$	CUM $AMCOST_{NRE}$
1	$37,500,000	$3,750,000	$75,000,000	$150,000,000	$15,000,000	$187,500,000
2	$75,000,000	$7,500,000	$150,000,000	$300,000,000	$30,000,000	$375,000,000
3	$112,500,000	$11,250,000	$225,000,000	$450,000,000	$45,000,000	$562,500,000
10	$375,000,000	$37,500,000	$750,000,000	$1,500,000,000	$150,000,000	$1,875,000,000

20	$750,000,000	$75,000,000	$1,500,000,000	$3,000,000,000	$300,000,000	$3,750,000,000
35	$1,312,500,000	$131,250,000	$2,625,000,000	$5,250,000,000	$525,000,000	$6,562,500,000
50	$1,875,000,000	$187,500,000	$3,750,000,000	$7,500,000,000	$750,000,000	$9,375,000,000

Software Development and Maintenance in a Systematic Reuse Environment

Following the above assumptions, the cost for developing and maintaining software in a reuse environment for a single and various multiples of systems is shown in the table below:

Table 3 Software Development Reuse Enviornment Over 10 years

	500,000 SLOC			2,000,000 SLOC		
No. Systems	$COST_R$	$AMCOST_R$	CUMM $AMCOST_R$	$COST_R$	$AMCOST_R$	CUM $AMCOST_R$
1	$66,375,000	$2,640,000	$92,775,000	$265,500,000	$10,560,000	$371,100,000
2	$77,625,000	$3,780,000	$115,425,000	$310,500,000	$10,620,000	$416,700,000
3	$88,875,000	$3,795,000	$126,825,000	$355,500,000	$10,680,000	$462,300,000
10	$167,625,000	$3,900,000	$206,625,000	$670,500,000	$11,100,000	$781,500,000

20	$280,125,000	$4,050,000	$320,625,000	$1,120,500,000	$11,700,000	$1,237,500,000
35	$448,875,000	$4,275,000	$491,625,000	$1,795,500,000	$12,600,000	$1,921,500,000
50	$617,625,000	$4,500,000	$662,625,000	$2,470,500,000	$13,500,000	$2,605,500,000

Software Cost Comparison for Reuse and Non-reuse

Table 4 illustrates how reuse and non-reuse system development and maintenance compared over a period of ten years.

Deviation of Development Maintenance Cumulative

Table 4 Cumulative Deviation Over 10 years

	500,000 SLOC			2,000,000 SLOC		
No. Systems	$COST_{NRE-R}$	$AMCOST_{NRE-R}$	CUMM Deviation	$COST_{NRE-R}$	$AMCOST_{NRE-R}$	CUMM Deviation
1	-$28,875,000	$1,110,000	-$17,775,000	-$115,500,000	$4,440,000	-$183,600,000
2	-$2,625,000	$3,720,000	$34,575,000	-$10,500,000	$19,380,000	-$41,700,000

3	$23,625,000	$7,455,000	$98,175,000	$94,500,000	$34,320,000	$100,200,000
10	$207,375,000	$33,600,000	$543,375,000	$829,500,000	$138,900,000	$1,093,500,000
20	$469,875,000	$70,950,000	$1,179,375,000	$1,879,500,000	$288,300,000	$2,512,500,000
35	$863,625,000	$126,975,000	$2,133,375,000	$3,454,500,000	$512,400,000	$4,641,000,000
50	$1,257,375,000	$183,000,000	$3,087,375,000	$5,029,500,000	$736,500,000	$6,769,500,000

LIMITATIONS

This work does not represent a rigorous economic cost-benefit analysis. It ignores the time value of funds and timing of implementations. Lines of code have known limitations as predictors of software cost. Accurate information about the cost of developing and maintaining existing systems is difficult to gather and in some cases just does not exist. However, these limitations do not invalidate the obvious trend in the analysis.

CONCLUSIONS

Using the assumptions mentioned above, we derived estimated cost avoidance from pursuing a reuse approach assuming 500,000 lines of code and 2.0 million lines of code in the product line. We derived these estimates for varying number of participating facilities, with the nominal number being 10. Our results shown graphically in Figures 1 and 2. A very conservative interpretation of the results is that if the PLA of system development were adopted for 500,000 lines of code at only ten sites, we will break even after the development of 3 systems. There will be savings of 207 million dollars in software development costs and 543 million dollars over ten years in cumulative development and maintenance cost. These savings compare to experiential data from product line success stories [TENA,3]. According to this study, we can conclude that there are significant developmental and maintenance cost savings in systematic software reuse and PLA.

Figure 1 Cost Avoidance of Development Reuse Software for 500,000 SLOC Over a Period of 10 Years

Figure 2 Cost Avoidance of Development Reuse Software for 2,000,000 SLOC Over a Period of 10 Years

ACRONYMS

AFFTC Air Force Flight Test Center

AFWTF Atlantic Fleet Weapons Training Facility

APG-ATC Aberdeen Proving Ground-Aberdeen Test Center

AUTEC Atlantic Undersea Test & Evaluation Center

EPG Electronic Proving Ground

LOC Lines of Code

NAWC Naval Air Warfare Center

NAWC-WPNS Naval Air Warfare Center-Weapons Division

PLA Product Line Approach

ROM Raw Order of Magnitude

SLOC Software Lines of Code

WSMR White Sands Missile Range

REFERENCES

[TENA, 1] Baseline Project Report, Volume X, Supporting Documents, Software Cost Analysis Survey, 1997

[TENA, 2] Baseline Project Report, Volume X, Supporting Documents, MITRE Cost Data Sheets, 1997.

[TENA, 3] Baseline Project Report, Volume II, Product Line Approach, Appendices C, D, E, 1997.